(12)

Special Report 82-4

March 1982

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Preliminary assessment of the nutrient film technique for wastewater treatment

John R. Bouzoun and Antonio J. Palazzo

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER Special Report 82-4	2. GOVT ACCESSION NO. AD-A115 425	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PRELIMINARY ASSESSMENT OF THE NUTRIENT FILM TECHNIQUE FOR WASTEWATER TREATMENT		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) John R. Bouzoun and Antonio J. Palazzo		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DA Project 4A762730AT42, Task Area D, Work Unit 18
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		12. REPORT DATE March 1982 13. NUMBER OF PAGES 19
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Hydroponics
Thin films
Wastes (Sanitary engineering)
Wastewater

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An experiment was conducted to determine the feasibility of using a solar powered, self-regenerating plant growth system, called the nutrient film technique (NFT), to treat primary effluent (average temperature, 11.1°C). Primary effluent was pumped onto the elevated end of a sloping waterproof 2-x 40-ft plywood tray and trickled through the root mat of reed canarygrass. The quantity of influent and effluent was measured as well as temperature, pH, total suspended solids, volatile suspended solids, BOD_5, total nitrogen, ammonia nitrogen, nitrate nitrogen, total phosphorus, phosphate phosphorus, and fecal coliform organisms. The quantity and quality of the reed canarygrass was determined from samples taken from six harvests. Mass balances are presented for BOD_5, total suspended solids, total nitrogen, ammonia nitrogen, total phosphorus, and phosphate phosphorus. The removal of several volatile trace organic compounds was determined on two separate dates.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

PREFACE

This report was prepared by John R. Bouzoun, Environmental Engineer, of the Civil Engineering Research Branch, Experimental Engineering Division, and Antonio J. Palazzo, Research Agronomist, of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this research was provided by DA Project 4A762730AT42, *Design, Construction, and Operations Technology for Cold Regions,* Task D, *Cold Regions Base Support: Design and Construction,* Work Unit 18, *Small Scale Systems for Waste Management, Water Conservation, and Reuse in Cold Regions.*

S. Reed, C.J. Martel and R. Sletten of CRREL technically reviewed the manuscript of this report. T. Jenkins of CRREL was responsible for the nutrient and trace organic analysis and provided valuable advice and assistance throughout the experiment. P. Butler of CRREL conducted the BOD, solids, and coliform analysis and assisted in operating and maintaining the experimental unit. Dr. W. Jewell of Cornell University originally proposed the experiment and provided the reed canarygrass. His advice throughout the experiment is gratefully acknowledged.

CONTENTS

ILLUSTRATIONS

TABLES

PRELIMINARY ASSESSMENT OF THE NUTRIENT FILM TECHNIQUE FOR WASTEWATER TREATMENT

John R. Bouzoun and Antonio J. Palazzo

INTRODUCTION

The nutrient film technique (NFT) is best described as a modified hydroponic system in which a thin film of nutrient solution flows through the root mat of plants growing without soil on an impermeable and slightly inclined surface. The major difference between an NFT system and a hydroponic plant system is in the depth of the nutrient solution. In the NFT the depth of the nutrient solution is not more than a few millimeters, whereas in hydroponic systems the entire root system is commonly submerged in the nutrient solution.

The NFT had its beginning as a research technique in 1966 and was developed for commercial use in subsequent years by Dr. Alan J. Cooper at the Glasshouse Research Institute in England (Cooper 1976). As a result of his research, Cooper (1974) has stated that the slope of NFT units is not critical but should be at least 1%. He has also reported (Cooper 1978) that it is possible to successfully raise tomatoes with ambient air temperatures as low as 7°C as long as the nutrient solution remains warm (25.5°C). Researchers have also shown that excellent crop yields are possible at low nutrient levels. Windsor and Massey (1978) reported that tomatoes grown in a nutrient solution with 10 parts per million of nitrogen were as vigorous as those grown in a nutrient solution with 85 parts per million of nitrogen. They also reported that root growth was actually increased at the low nitrogen levels.

Two characteristics of the NFT make it a potentially attractive process for wastewater treatment. The first is the thin layer of nutrient solution (wastewater) that passes through the root mat, which allows the rate of oxygen diffusion into the wastewater and to the plant roots to be high enough that nutrient uptake is not inhibited. The second characteristic is that the root mat acts as a very effective filter of the nonsoluble fraction of the oxygen-demanding substances and nutrients in the wastewater. Also the portion of the root mat in the wastewater should provide an excellent site on which the bacteria that will oxidize the soluble fraction of the organics can attach themselves.

Purpose

The purpose of this report is to present the results of an experiment conducted at CRREL to determine the feasibility of using the nutrient film technique to treat primary sewage effluent while producing a usable crop.

Scope

The experiment discussed in this report was conducted on a pilot scale from February through June of 1980. During that period, primary effluent was applied at three volumetric loading rates to an NFT test unit containing reed canarygrass. Grab samples of the applied wastewater and the NFT effluent were analyzed for biochemical oxygen demand (BOD), suspended solids (SS), and nutrients. The reed canarygrass was harvested six times during the study to determine its quantity and quality. This report presents the data collected during the experiment and a brief discussion of the removal of the various wastewater parameters that were measured. Subsequent studies, currently underway, are designed to give a more complete understanding of removal mechanisms and to develop initial engineering design criteria.

MATERIALS AND METHODS

NFT units

Our initial work with the NFT began with the construction and installation of the trays and plumbing in the CRREL greenhouse in late November 1979. Two trays, each 6.1 m long, 0.6 m wide, and 0.5 m deep, were constructed from plywood and lined with heavy plastic. The combined surface area of both trays was 7.4 m^2. The trays were placed at a slope of 5% in such a way that the runoff from the first tray flowed onto the high end of the second tray (Fig. 1).

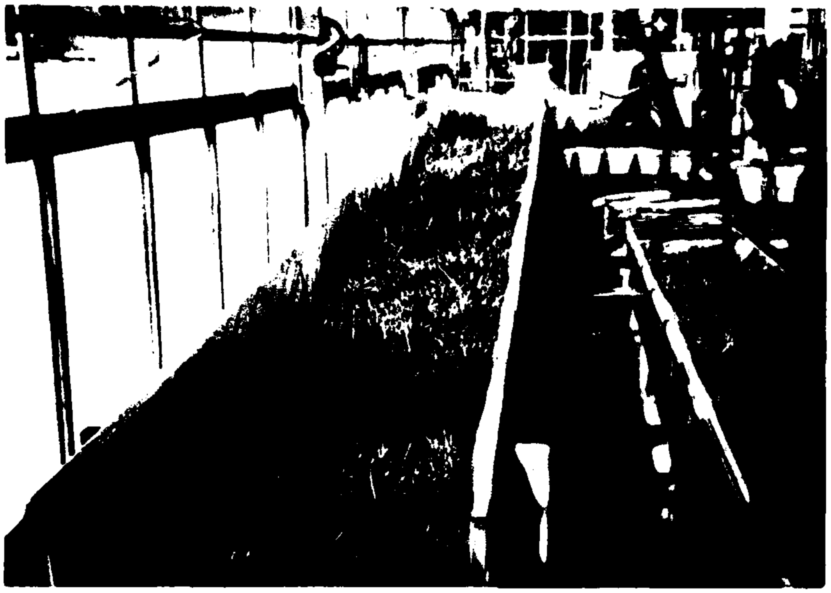

Figure 1. CRREL experimental NFT unit.

A submersible pump in an outdoor storage tank pumped the wastewater into the greenhouse and onto the NFT unit. An industrial timer, capable of providing both on and off times ranging from zero to 60 minutes, controlled the wastewater delivery pump and hence the application schedule to the NFT unit. We installed a ball valve and a flowmeter in the influent line ahead of the point where it discharged onto the NFT unit, which enabled us to measure and adjust the volume of wastewater pumped onto the unit during each cycle.

The effluent from the NFT ran into a trough at the end of the second tray and was collected in a holding tank. A float-actuated submersible pump discharged the effluent from this tank, through a flowmeter and back into the sewer. The flowmeter allowed us to measure both the quantity and rate of runoff from the unit.

During late November 1979 reed canarygrass sod was cut from an established stand at Cornell University in Ithaca, New York, and delivered to CRREL. The roots were washed to remove the soil, and the sod was placed in the NFT trays and kept moist with tap water until the plumbing and electrical work was completed. Wastewater application began on a daily basis on 15 February 1980 and continued, with a few interruptions due to mechanical failures, until 25 June 1980.

Wastewater application rates

During the study three different wastewater application volumes were used, as shown in Table 1. These daily application rates of 378.5, 757.0, and 1514.0 L/day are equal to 5.1, 10.2 and 20.4 cm/day respectively on the surface of the unit.

Table 1. Wastewater application schedule and daily volumes (wastewater was applied 24 hr/day, 7 days/week).

Dates	*Flow (L/min)*	*On/off time (min)*	*Daily volume (L)*
18 Feb 80–11 Apr 80	3.2	5/50	378.5
12 Apr 80–13 Jun 80	3.2	10/50	757.0
14 Jun 80–25 Jun 80	3.2	20/40	1514.0

Wastewater sampling and analysis

Between 21 February and 25 June 1980, grab samples of the applied wastewater and the effluent were taken three times per week and analyzed for BOD. During the same time period, samples were analyzed twice per week for total suspended solids and once per week for volatile suspended solids and fecal coliform bacteria. From 15 February through 12 May 1980, biweekly samples were analyzed for

nitrogen and phosphorus. Throughout the study, the flow, temperature, pH and turbidity of the applied wastewater and the effluent were measured five times per week. The maximum and minimum greenhouse temperatures were recorded daily. Twice during the study, on 3 and 8 April, the applied wastewater was spiked with several volatile trace organic compounds; samples were collected at the point of application, the midpoint, and the end of the unit, and were analyzed for these substances.

Reed canarygrass harvests

The reed canarygrass was harvested six times during the study on the following dates: 3 March 1980, 18 March 1980, 11 April 1980, 1 May 1980, 22 May 1980, 17 June 1980. The grass was cut back to a height of approximately 5 cm, and the cuttings were weighed to determine their fresh weight. Two fresh subsamples from each tray were weighed, dried in an oven and reweighed to obtain the percentage moisture and the dry weight yield from the entire unit. A sample of this dry plant matter was then analyzed for protein, nutrient, cation, and metal content.

Analytical methods

Wastewater samples were analyzed by the methods presented in Martel et al. (1982) and Jenkins et al. (1981). The grass samples were analyzed according to Liegel and Schulte (1977).

RESULTS

Data

Appendix A contains the data collected during the study. Table 2 gives the characteristics of the applied wastewater.

Water volumes

The daily variability of the volume of applied wastewater can be attributed to clogging of the ball valve used to control the flow rate of wastewater onto the system and clogging of holes in the distribution pipe with solids. The influent and effluent flow meters were also affected several times by solids during the study.

BOD removal

The influent and effluent BOD data are plotted in Figure 2. Between days 7 and 132 we estimate that 6910 g of BOD (73.8 kg/ha day) was applied to the system and 1281 g was present in the effluent. This gives a mass removal of BOD of 81%.

On 6 and 7 March we ran BOD analyses on both filtered and unfiltered samples of the applied wastewater and the effluent. The results are given in Table 3. On 6 March, based on concentrations, the soluble BOD was reduced 87% and the nonsoluble BOD was reduced 92%. On 7 March, again based on concentrations, the soluble BOD was reduced 79% and the nonsoluble BOD was reduced 95%.

Total suspended solids removal

The total suspended solids data are plotted in Figure 3. Between days 8 and 127 approximately 5882 g of total suspended solids (65.0 kg/ha day) was applied to the system and 1478 g was present in the effluent. This represents a mass removal of approximately 75% of the total suspended solids applied to the system.

Table 2. Characteristics of applied wastewater.

	Mean	*Standard deviation*	*Number of measurements*
Temperature, °C	11.1	2.5	77
pH	7.0	0.5	77
Turbidity, JTU*	45.8	20.6	77
Total suspended solids, mg/L	98.8	86.2	40
Volatile suspended solids, mg/L	87.5	71.0	17
BOD_5, mg/L	110.0	58.8	42
F. coliform, colonies/100 mL	7.9×10^5	4.2×10^5	13
Total P as P, mg/L	6.1	2.3	21
Phosphate as P, mg/L	6.0	1.8	22
Total N as N, mg/L	34.7	11.8	22
Ammonium as N, mg/L	27.7	8.7	22
Nitrate as N, mg/L	0	0	22

*Jackson turbidity units

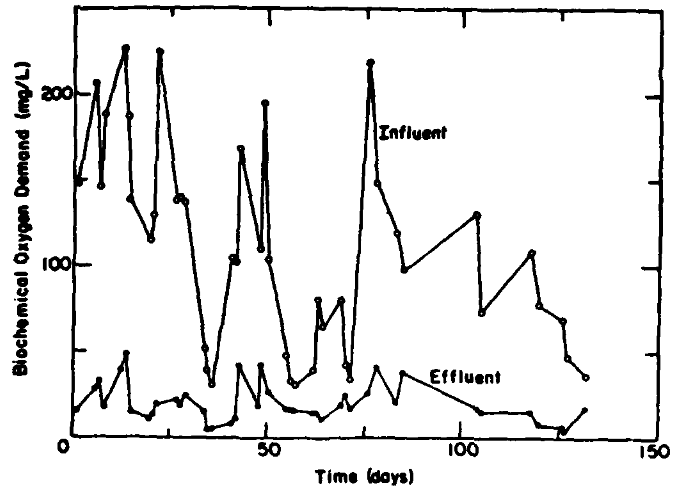

Figure 2. Influent and effluent BOD.

Table 3. Total, soluble, and nonsoluble BOD.

Date	Applied wastewater BOD (mg/L)			Effluent BOD (mg/L)		
	Total*	Soluble†	Non-soluble**	Total*	Soluble†	Non-soluble**
6 March	130.5	69.0	61.5	14.1	9.2	4.9
7 March	225.0	58.5	166.5	19.8	12.3	7.5

* Non-filtered
† Filtered
**Non-filtered minus filtered

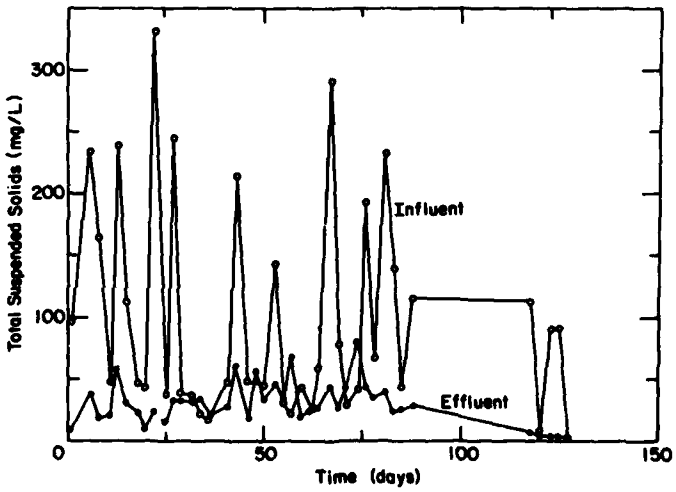

Figure 3. Influent and effluent total suspended solids.

Nitrogen removal

The total nitrogen data are plotted in Figure 4. As shown in Table 4, 1239 g (22.4 kg/ha day) of total nitrogen was applied to the system between days 11 and 88, and 370 g (6.4 kg/ha day) was removed by the system. This gives an overall mass removal of 29.9%. Of the 370 g removed, 241 g (4.2 kg/ha day) was not accounted for. The balance of 129 g (2.2 kg/ha day) was in the harvested portion of the reed canarygrass.

During the same time period 993 g of ammonia nitrogen was applied to the system and 655 g was

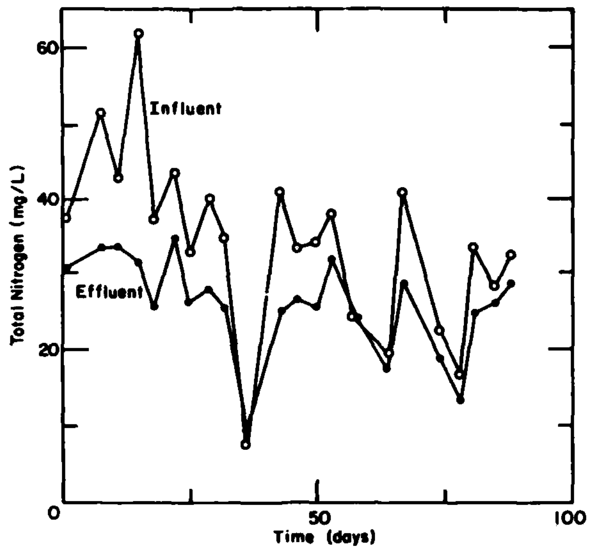

Figure 4. Influent and effluent total nitrogen.

Table 4. Total nitrogen budget, days 11 through 88.

	Mass loading (g)	*Mass loading rate (kg/ha day)*	*Percent of applied*	*Percent of removed*
Applied	1239	21.4	100.0	N/A
Runoff	869	15.0	70.1	N/A
Removed	370	6.4	29.9	100.0
Unaccounted for	241	4.2	19.5	65.2
Plant harvest	129	2.2	10.4	34.8

present in the runoff. This represents an overall mass removal of 34%.

The applied wastewater did not contain any nitrate nitrogen. The nitrate nitrogen concentration in the effluent was between 0 and 10 mg/L. Approximately 134 g of nitrate nitrogen was present in the runoff from the system during the same time period.

Between days 11 and 88 approximately 246 g of organic nitrogen was applied to the system and 80 g remained in the effluent. This results in a mass removal of 67.5%.

Phosphorus removal

The total phosphorus data are plotted in Figure 5. As shown in Table 5, 212 g (3.7 kg/ha day) of total phosphorus was applied to the system between days 11 and 88, and 44 g (0.8 kg/ha day) was removed to give an overall mass removal of 20.8%. Of the 44 g removed, 26 g (0.5 kg/ha day) was not accounted for, and 18 g (0.3 kg/ha day) was in the harvested portion of the reed canarygrass.

During the same time period 164 g of orthophos phate was applied to the system and 18 g removed to give an overall mass removal of 10.9%.

Fecal coliform removal

The fecal coliform counts of the applied wastewater and effluent are plotted in Figure 6. Generally the fecal coliform count was reduced 90% or more. The fecal coliform counts in the effluent were in the tens of thousands.

Removal of volatile trace organics

The results of two experiments to determine the ability of the experimental NFT unit to remove volatile trace organics are given in Table 6.

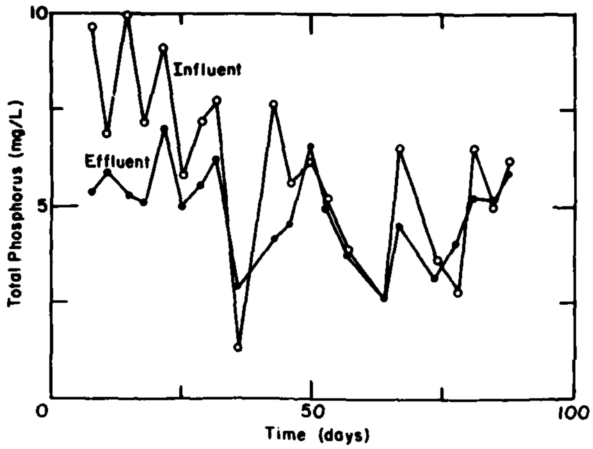

Figure 5. Influent and effluent total phosphorus.

Table 5. Total phosphorus budget, days 11 through 88.

	Mass loading (g)	*Mass loading rate (kg/ha day)*	*Percent of applied*	*Percent of removed*
Applied	212	3.7	100.0	N/A
Runoff	168	2.9	79.2	N/A
Removed	44	0.8	20.8	100.0
Unaccounted for	26	0.5	12.3	59.1
Plant harvest	18	0.3	8.5	40.9

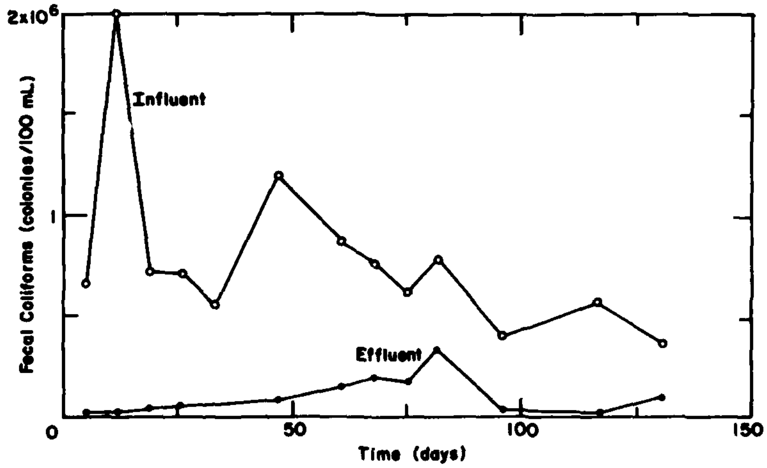

Figure 6. Influent and effluent fecal coliforms.

Table 6. Removal of volatile trace organics ($\mu g/L$).

Substance	3 April 1980 (379 L/day) Applied	1/2	Runoff	8 April 1980 (757 L/day) Applied	1/2	Runoff
Acetone	22.9	12.8	4.37	-	-	-
Benzene	4.91	0.70	bd	-	-	-
Chlorobenzene	10.4	bd	bd	-	-	-
Chloroform	33.2	14.6	7.53	56.8	22.4	4.6
Ethyl acetate	2.97	bd	bd	-	-	-
Methylene chloride	3.22	0.54	bd	-	-	-
Methyl chloride	-	-	-	12.5	7.5	1.5
Pentane	1.89	0.41	bd	-	-	-
Tetrachloroethylene	2.09	0.31	bd	12.3	2.3	0.3
Toluene	71.0	26.6	0.47	16.4	5.0	0.3
1,1 dichloroethane	-	-	-	24.3	10.0	1.9

bd, below detectable limits

Reed canarygrass yields

Table 7 gives the fresh weight yields, the percentage dry matter, the dry weight yields, and the daily growth rates of the reed canarygrass during each growth period. The harvested reed canarygrass contained an average of 13.5% dry matter. Its growth rate ranged from 23.8 to 56.2 kg dry matter/ha day with an average growth rate of 40.9 kg dry matter/ha day. The daily growth rate more than doubled from the first harvest on 3 March 1981 to the next to the to the last harvest on 22 May 1981. Then, during the last growing period, the growth rate declined to 35.5 kg per hectare per day.

The total digestible nutrient content, the crude protein content, and the yields of crude protein in the reed canarygrass during each harvest period are given in Table 8. The concentrations of total digestible nutrients and crude protein averaged 80.7 and 35.1% respectively. The yields of crude protein ranged from 8.8 to 19.3 kg/ha day with an average of 14.2 kg of crude protein/ha day.

The nutrient concentrations of the reed canarygrass are given in Table 9. The nitrogen concentration in the harvested portion of the reed canarygrass ranged

Table 7. Yields and growth rates.

Harvest date	Days of growth	Fresh weight yield (g)	Percent dry matter	Dry matter yield (g)	Growth rate (kg/ha day)
4 Feb 80	-	-	-	-	-
3 Mar 80	28	3402	14.5	493	23.8
18 Mar 80	15	2949	13.3	392	35.3
11 Apr 80	24	6609	12.5	826	46.5
1 May 80	20	5990	12.0	719	48.6
22 May 80	21	6570	13.3	874	56.2
17 Jun 80	26	4361	15.5	676	35.1
			13.5±1.3		40.9±11.7

Table 8. Total digestible nutrient and crude protein concentrations.

Harvest date	Total digestible nutrients (%)	Crude protein (%)	Crude protein yield (g)	Crude protein yield (kg/ha day)
2 Mar 80	74.1	37.2	183.0	8.8
18 Mar 80	72.7	38.5	150.2	13.5
11 Apr 80	-	35.3	291.6	16.5
1 May 80	-	33.8	242.7	16.3
22 May 80	88.6	34.6	301.0	19.3
17 June 80	83.7	30.9	212.0	11.0

Table 9. Nutrient, cation, and metal content of the reed canarygrass (1980).

	N(%)	P(%)	K(%)	S(%)	Ca(%)	Mg(%)	B(ppm)	Zn(ppm)	Mn(ppm)	Fe(ppm)	Cu(ppm)	Mo(ppm)	Co(ppm)
3 Mar	5.89	0.76	4.00	0.49	0.46	0.23	27.4	50.1	380.6	437.2	19.9	<2.1	<1.8
18 Mar	5.94	0.74	4.20	0.51	0.35	0.20	20.0	55.1	365.4	196.1	16.5	<2.1	<1.8
11 Apr	5.96	0.70	4.14	0.44	0.40	0.22	10.9	61.0	341.3	202.4	23.3	<2.1	3.5
1 May	5.41	0.71	4.03	0.46	0.45	0.25	11.9	68.8	234.5	205.5	22.5	<2.1	3.3
22 May	5.10	0.58	2.95	0.46	0.51	0.23	9.9	47.3	272.7	183.6	13.1	<2.1	<1.8
17 Jun	4.46	0.58	3.66	0.48	0.69	0.28	21.0	55.4	199.7	223.2	15.6	<2.1	<1.8
Avg.	5.46	0.68	3.83	0.47	0.48	0.23	16.9	56.3	299.0	241.3	18.5	<2.1	<2.3

Table 10. Nitrogen uptake by reed canarygrass.

Harvest date	Nitrogen (%)	Nitrogen uptake (g)	Nitrogen uptake (kg/ha day)
3 Mar 80	5.89	29.0	1.4
18 Mar 80	5.94	23.2	2.1
11 Apr 80	5.64	46.6	2.6
1 May 80	5.41	38.8	2.6
22 May 80	5.10	44.4	2.8
17 Jun 80	4.46	30.6	1.6

Table 11. Phosphorus uptake by reed canarygrass.

Harvest date	Phosphorus (%)	Phosphorus uptake (g)	Phosphorus uptake (kg/ha day)
3 Mar 80	0.76	3.7	0.18
18 Mar 80	0.74	2.9	0.26
11 Apr 80	0.70	5.8	0.33
1 May 80	0.71	5.1	0.34
22 May 80	0.58	5.1	0.34
17 Jun 80	0.58	4.0	0.21

from 4.46 to 5.96%, with an average of 5.46%. During the study the nitrogen uptake rates ranged from 1.6 to 2.6 kg nitrogen/ha day, with an average of 2.2 kg/ha day (Table 10).

The phosphorus concentration in the reed canarygrass ranged from 0.58 to 0.76%, with an average of 0.68% (Table 9). The rate of phosphorus uptake ranged from 0.18 to 0.34 kg/ha day, with an average of 0.28 (Table 11).

As with nitrogen and phosphorus, the concentrations of other elements for which the reed canarygrass was analyzed are considered to fall within the general range necessary for plant growth (Allaway 1968). No visual symptoms of deficiencies or toxicities were noticed during the study.

DISCUSSION

General

Before discussing the results of this experiment, it is important to mention several factors that influenced the overall performance. Both the daily volumes of wastewater applied to the system and the pollutant concentrations fluctuated significantly. These variations negated the possibility of any extended steady-state loading periods during which kinetic rate data could be developed.

It is also important to consider that the mean temperature of the applied wastewater during the experiment was only 11.1°C, and that the study was conducted during the winter and spring months when the daily photoperiods were relatively short. These factors taken together represent a worst case situation.

BOD removal

As shown in Table 3, the removal of the nonsoluble fraction of the BOD due primarily to filtration by the plant roots and, to some degree, sedimentation due to the shallow depth of the wastewater was greater than the removal of the soluble BOD due to microbiological oxidation by the microorganisms attached to the plant roots. We anticipate that warmer wastewater temperatures will increase the rate of microbial oxidation.

The overall mass reduction of total suspended solids of 75% is also very good. The removal of suspended solids was due to filtration by the root mat and sedimentation. Jenkins et al. (1980) and Martel et al. (1980) have both demonstrated the relationship between solids and BOD removal for the overland flow system at CRREL. Figure 7, taken from Martel (1980), shows that the rapid decrease in suspended solids concentration within the first few meters of the overland flow slope is closely paralleled by a rapid reduction in BOD concentration. After this abrupt drop, further removal of solids is just about negligible while BOD removal, due primarily to microbiological oxidation, continues at a much slower rate. We believe that the same type of performance should be expected in the NFT unit. A buildup of solids did occur within the first meter or so of the NFT unit, and as previously mentioned, soluble BOD was removed less effectively than nonsoluble BOD.

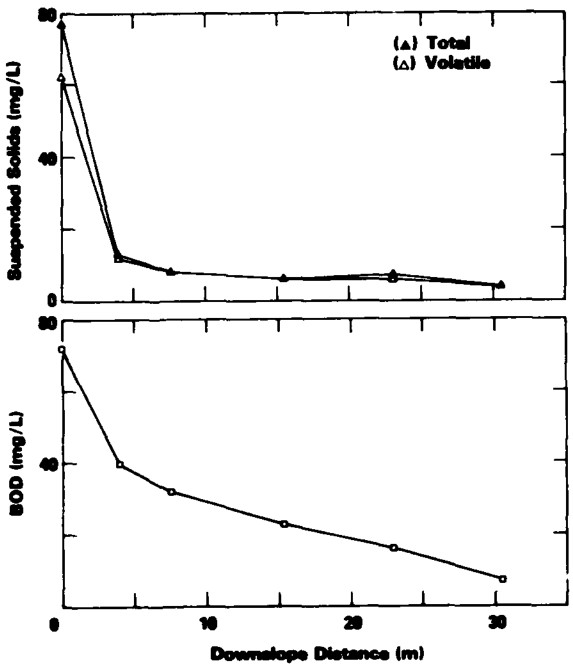

Figure 7. Concentration of BOD and suspended solids vs downslope distance (from Martel et al. 1980).

Nitrogen removal

As shown in Table 4, harvesting the reed canarygrass accounted for 10.4% of the total nitrogen applied to the system and 34% of the total nitrogen removed by the unit. The mass of unaccounted-for total nitrogen represents 19.5% of the total nitrogen that was applied to the system and 65.2% of the total nitrogen removed by the unit.

The 241 g of nitrogen that cannot be accounted for is very close to the 246 g of organic nitrogen that was applied to the system. Because organic nitrogen is contained primarily in the cellular material of the bacteria and other volatile solids in the wastewater, a large fraction of this unaccounted-for nitrogen was probably removed from the wastewater along with these solids. Also a fraction of the unaccounted-for nitrogen was in the root tissue of the reed canarygrass. Other mechanisms such as volatilization of ammonia and denitrification of nitrate nitrogen may have also contributed to the removal of nitrogen.

The average daily mass loading rate of 21.4 kg total nitrogen/ha (Table 4) gives a yearly loading rate of greater than 7800 kg/ha (assuming year-round operation of the system), which is considerably greater than the yearly nitrogen loading rate of most land treatment and aquaculture wastewater treatment systems. Also, the average yield of reed canarygrass on a dry weight basis was 40.9 kg/ha day (Table 7) and the average concentrations of crude protein and total digestible nutrients were 35.1 and 80.7% respectively (Table 8), which would indicate that the reed canarygrass was utilizing the nitrogen very effectively and efficiently.

Phosphorus removal

Table 5 shows that harvesting the reed canarygrass accounted for 8.5% of the total phosphorus that was applied to the system and 40.9% of the total phosphorus that was removed by the unit. The mass of total phosphorus unaccounted for represents 12.3% of the amount applied to the system and 59.1% of the total phosphorus removed by the system.

The 26 g of total phosphorus not accounted for was most likely incorporated into the roots of the reed canarygrass, used as a microbial substrate, and removed along with the solids.

The average daily loading rate of 3.7 kg total phosphorus/ha gives a yearly rate of 1350 kg/ha. This loading rate is far greater than the yearly phosphorus loading rate at most land treatment or aquaculture wastewater treatment systems. Also the average phosphorus concentration of the harvested reed canarygrass was 0.68%, which is very high, and indicates that the reed canarygrass utilized the applied phosphorus very effectively, and simply did not require additional phosphorus to sustain itself.

Fecal coliform removal

The removal of fecal coliform bacteria was most likely due to the filtration of the solids. Other mechanisms, such as desiccation during the drying cycles, predation by higher forms of microorganisms, and exposure to ultraviolet radiation, may have then contributed to their reduction.

Volatile trace organics removal

The results of the two experiments given in Table 6 show excellent removal of the volatile trace organics added to the applied wastewater. In both experiments the concentration of every organic compound was reduced more than 90% as it passed through the experimental unit. Several were reduced below the detectable limits of the analytical equipment. There are several mechanisms that could have been responsible for the reductions in the concentrations of these trace organics. However, based on previous work with trace organics removal by overland flow (Jenkins et al. 1981) and the similarities between the NFT and overland flow, we feel that volatilization was the most likely mechanisms. Additional studies will have to be conducted to confirm this and to determine the

kinetic rate constants for the removal of the various organic compounds.

Reed canarygrass

The reed canarygrass served four major purposes. First, its roots filtered the solids out of the applied wastewater. Second, its roots served as a site for microorganisms to attach themselves. Third, it utilized the nitrogen and phosphorus in the applied wastewater for its growth. Fourth, the harvested grass was a usable forage crop.

The average growth rate of the reed canarygrass of 40.9 kg dry matter/ha day was very good. The exact reason for the decline in the growth rate prior to the last harvest is not known. Two possible causes are heat stress due to very high greenhouse temperatures in the late spring and the thickness of the microbial slime on the roots that prevented the nutrients in the wastewater from reaching the roots. Further studies will have to be conducted to determine if the late decline in growth rate will be a recurring problem, and if it is, what the possible solutions are.

The average concentrations of total digestible nutrients and of crude protein which were 80.7 and 35.1%, respectively, are considerably higher than the standard of 65% total digestible nutrients and 15% crude protein, above which is considered to be excellent quality hay (Barnes 1975).

The concentrations of the nitrogen and phosphorus in the reed canarygrass were considerably higher than what is found in the grass harvested from sites irrigated with wastewater. The average daily uptake rates of 2.2 and 0.28 kg/ha day of nitrogen and phosphorus give annual uptake rates of 803 and 102 kg/ha. As was the case with the concentrations of N and P, these annual uptake rates are very high when compared to what has been reported for land treatment systems where wastewater has been used to irrigate reed canarygrass.

CONCLUSIONS

As a result of the experiment discussed in this report the following major conclusions can be made:

1. The nutrient film technique can be used to treat cold primary effluent to secondary levels at very high hydraulic loadings.
2. The nutrient film technique will remove a portion of the nitrogen and phosphorus from primary effluent.
3. The nutrient film technique can significantly reduce the levels of several volatile trace organic compounds in primary effluent.
4. The nutrient film technique can produce a large amount of very high quality forage grass, even during periods of short daylight.

Even though this first study of using the NFT to treat primary wastewater has demonstrated the feasibility of the concept, many questions must be answered before any large-scale use of the NFT concept is implemented. Among these are

1. What will be the costs (both capital and operating and maintenance) of an NFT wastewater treatment facility and how will they compare to those of conventional treatment systems?
2. What types of crops can be grown with the NFT?
3. What is the longevity of a specific crop?
4. Will certain crops be better than others in removing certain pollutants from wastewater?
5. Can equations be developed to predict the removal rates of specific pollutants as a function of the hydraulic loading rates and pollutant concentrations in the applied wastewater?
6. What will be the energy budget of an NFT installation?
7. What are the effects of air temperature, light intensity and duration, and wastewater temperature on pollutant removal rates?
8. What are the differences, in terms of system performance, between applying a given volume of wastewater per day continuously or intermittently?

LITERATURE CITED

Allaway, W.H. (1968) Agronomic controls over Environmental cycling of trace elements. *Advances in Agronomy*, vol. 20, p. 235-274.

Barnes, R.F. (1975) Forage testing and its applications. In *Forages* (M.H. Heath, ed.). Ames, Iowa: Iowa University Press, p. 654-663.

Cooper, A.J. (1974) Hardy nursery stock production in nutrient film. *The Grower*, 81.

Cooper, A.J. (1976) *Nutrient film technique of growing crops.* London: Grower Books.

Cooper, A.J. (1978) *Commercial applications of NFT.* London: Grower Books.

Jenkins, T.F., D.C. Leggett, C.J. Martel, R.E. Peters, and C.R. Lee (1980) Toxic volatile organics removal by overland flow. *Proceedings of the Research Symposia, Water Pollution Control Federation Convention*, Las Vegas, Nevada.

Jenkins, T.F., D.C. Leggett, C.J. Martel and H.E. Hare 1981) Overland flow: Removal of volatile organics. CRREL Special Report 81-1. ADA097576.

Liegel, E.A. and E.E. Schulte (1977) Wisconsin soil testing and plant analysis procedures. University of Wisconsin Soil Fertility Series, no. 6, Madison, Wisconsin.
Martel, C.J., D.D. Adrian, T.F. Jenkins, and R.E. Peters (1980) Rational design of overland flow systems. In *Proceedings of the ASCE National Environmental Engineering Conference*, New York.
Martel, C.J., J.R. Bouzoun, and T.F. Jenkins (1980) Removal of organics by overland flow. Presented at US EPA National Seminar on Overland Flow, Dallas, Texas.
Martel, C.J., T.F. Jenkins, C.J. Diener and P.L. Butler (1982) Development of a rational design procedure for overland flow systems. CRREL Report 82-2.
Windsor, G.W. and D.J. Massey (1978) Some aspects of the nutrition of tomatoes grown in recirculating solution. *Acta Horticulcurae*, vol. 82.

APPENDIX A. EXPERIMENTAL DATA.

Date	Day no.	Flow liters applied	Flow liters runoff	Sewage temp. °C applied	Sewage temp. °C runoff	pH applied	pH runoff	Turbidity JTU applied	Turbidity JTU runoff	TSS mg/L applied	TSS mg/L runoff	VSS mg/L applied	VSS mg/L runoff	BOD_5 mg/L applied	BOD_5 mg/L runoff	Total N mg/L applied	Total N mg/L runoff	NH_3-N mg/L applied	NH_3-N mg/L runoff	NO_3-N mg/L applied	NO_3-N mg/L runoff	Total P mg/L applied	Total P mg/L runoff	PO_4-P mg/L applied	PO_4-P mg/L runoff	F. Col. no./100 ml applied	F. Col. no./100 ml runoff
15 Feb	1	367.9	--	9.0	14.0	7.0	7.3	51	8.6	97	10	--	--	148.5	15.9	37.9	31.4	37.9	31.4	0	0.7	--	--	6.1	6.1	--	--
16	2	241.5	204.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17	3	241.5	204.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
18	4	241.5	204.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
19	5	241.5	204.8	9.0	14.0	7.2	7.1	39	19	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.6×10^5	0.24×10^5
20	6	276.3	260.4	8.5	15.0	6.9	7.1	70	16	235	39.4	211	22.8	207	28.8	--	--	--	--	--	--	--	--	--	--	--	--
21	7	295.2	270.3	8.5	16.0	7.1	7.3	56	16	--	--	--	--	145.5	33	--	--	--	--	--	--	--	--	--	--	--	--
22	8	386.4	339.5	9.0	13.0	7.0	7.3	57	8.9	165	18.7	--	--	187.5	17.7	51.9	34.1	33.9	28.3	0	1.3	9.7	5.4	9.7	5.4	--	--
23	9	33.7	300.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
24	10	332.7	300.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
25	11	332.7	300.5	8.5	14.0	7.4	7.2	37	9.5	47.6	21.6	--	--	--	--	43	34.2	34.9	28.1	0	1.7	6.9	5.9	5.3	5.1	--	--
26	12	277.4	217.3	9.0	13.5	7.1	7.2	65	11	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	20×10^5	0.26×10^5
27	13	95.8	67.4	8.0	12.5	7.0	6.9	70	19	240	58.7	210	34.7	226.5	40.2	--	--	--	--	--	--	--	--	--	--	--	--
28	14	168.4	109.0	8.5	14.0	7.2	7.0	55	35	--	--	--	--	187.5	49.5	--	--	--	--	--	--	--	--	--	--	--	--
29	15	339.9	--	9.0	12.0	8.3	7.2	47	11	113.4	31.4	--	--	138.6	15	62.6	32.2	44.9	26.1	0	1.9	10	5.3	6.5	4.4	--	--
1 Mar	16	342.9	293.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2	17	342.9	293.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3	18	342.9	293.7	9.0	12.0	7.6	7.0	39	9.9	47	23.2	--	--	--	--	37.6	26	30.8	19.3	0	1.9	7.2	5.1	6	4.3	--	--
4	19	394.4	371.3	9.0	13.5	7.6	6.9	35	9.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.2×10^5	0.46×10^5
5	20	410.3	341.0	10.0	14.0	7.3	7.1	37	7.7	44	10.7	10.7	7.1	114	11.7	--	--	--	--	--	--	--	--	--	--	--	--
6	21	362.6	342.2	10.0	15.0	7.2	7.0	37	7	--	--	--	--	130.5	14.1	--	--	--	--	--	--	--	--	--	--	--	--
7	22	391.0	347.1	9.5	15.0	7.2	7.1	84	11	331	24	--	--	225	19.8	44.1	35.5	33.9	27.3	0	2.3	9.2	7.1	7.3	6.1	--	--
8	23	400.0	346.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9	24	400.0	346.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
10	25	400.0	346.7	8.5	13.5	7.5	7.1	33	5.7	38	16	--	--	--	--	33	26.7	27.1	20	0	2.7	5.8	5	4.6	4.3	--	--
11	26	351.6	319.8	9.0	15.0	7.3	6.8	32	8.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.1×10^5	0.55×10^5
12	27	526.1	458.0	8.0	12.5	7.0	6.7	63	13	246	32.6	224	19.7	138	22.5	--	--	--	--	--	--	--	--	--	--	--	--
13	28	312.0	227.5	8.5	13.5	7.3	7.1	94	7.8	--	--	--	--	141	19.5	--	--	--	--	--	--	--	--	--	--	--	--
14	29	311.5	271.0	9.0	14.0	6.9	6.6	45	17	39	32.2	--	--	137	25.8	40.6	28.5	35.4	21.5	0	5.1	7.3	5.6	5.3	4.6	--	--
15	30	426.9	392.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16	31	426.9	392.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17	32	426.9	392.1	8.5	14.0	7.2	6.7	37	14	37	31.8	--	--	--	--	35.4	26.2	29.5	19.7	0	5	7.8	6.3	5.8	5.4	--	--
18	33	351.6	336.9	9.0	16.0	6.9	6.5	33	8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5.5×10^5	--
19	34	336.9	316.0	8.0	14.0	6.6	6.3	20	12	22.3	34.6	16.6	18.3	52.2	15.9	--	--	--	--	--	--	--	--	--	--	--	--
20	35	394.0	323.2	9.5	8.0	6.5	6.3	17	6.2	--	--	--	--	40.2	5.4	--	--	--	--	--	--	--	--	--	--	--	--
21	36	393.6	384.2	8.5	16.0	6.3	6.0	14	6	18.1	20.6	--	--	30.6	6	8	9.7	4.9	2.1	0	5.5	1.3	2.9	1.2	2.4	--	--
22	37	64.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
23	38	64.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
24	39	64.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
25	40	397.8	--	9.0	16.0	6.9	6.4	44	21	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
26	41	400.1	373.6	9.0	15.0	7.2	6.5	39	8	49	29	43	16.3	105	9	--	--	--	--	--	--	--	--	--	--	--	--
27	42	279.0	275.5	11.0	16.0	7.0	6.9	35	12	--	--	--	--	102	11.7	--	--	--	--	--	--	--	--	--	--	--	--
28	43	526.1	446.6	8.5	9.5	7.0	6.9	77	26	215	62.3	--	--	168	43.2	41.5	25.5	26.9	20.8	0	2.3	7.7	4.2	4.2	3.3	--	--
29	44	520.4	471.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
30	45	520.4	471.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
31	46	520.4	471.2	9.0	15.0	7.2	6.9	36	6.6	49	19.3	--	--	--	--	33.9	27.1	29.2	19.2	0	5.5	5.6	4.6	4.3	4.1	--	--
1 Apr	47	416.6	373.6	10.0	14.0	7.1	6.9	33	9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	12×10^5	0.85×10^5
2	48	451.9	370.9	9.0	15.0	7.2	7.1	33	15	--	57	35	31	110	19.2	--	--	--	--	--	--	--	--	--	--	--	--
3	49	390.2	374.3	9.0	16.0	7.4	6.9	47	13	--	--	--	--	195	43.5	--	--	--	--	--	--	--	--	--	--	--	--
4	50	359.6	303.2	9.0	15.0	7.1	6.9	37	13	45.9	34.4	--	--	104	27	34.7	25.8	28	17.2	0	4.9	6.2	6.6	4.8	6	--	--
5	51	416.7	377.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Date	Day no.	Flow liters		Sewage temp. °C		pH		Turbidity JTU		TSS mg/L		VSS mg/L		BOD_5 mg/L		Total N mg/L		NH_3-N mg/L		NO_3-N mg/L		Total P mg/L		PO_4-P mg/L		F. Col. no./100 ml	
		applied	runoff	applied	runoff	applied	runoff	applied	runoff	applied	runoff	applied	runoff	applied	runoff	applied	runoff	applied	runoff	applied	runoff	applied	runoff	applied	runoff	applied	runoff
6 Apr	52	416.7	377.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7	53	416.7	377.0	11.0	8.5	7.3	6.9	46	18	144	47.3	--	--	--	--	38.5	32.4	30.2	23.5	0	4.4	5.2	5	4	3.6	--	--
8	54	378.5	336.9	10.0	10.0	7.0	6.8	49	18	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9	55	381.5	384.2	11.0	15.0	7.1	6.6	44	17	32.1	34.4	30.1	21.8	48	16.9	--	--	--	--	--	--	--	--	--	--	--	--
10	56	374.7	376.6	11.0	16.0	8.0	6.6	23	17	--	--	--	--	34	16.9	--	--	--	--	--	--	--	--	--	--	--	--
11	57	444.4	427.7	11.0	15.0	7.2	6.8	42	25	20.9	69	--	--	31.5	16.8	24.8	25.2	21.8	12	0	10	3.9	3.8	3.3	2.7	--	--
12	58	949.7	897.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
13	59	949.7	897.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
14	60	949.7	897.0	12.5	15.5	7.1	6.9	24	6.3	45.1	21.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
15	61	655.6	652.9	12.0	15.0	7.0	6.6	39	8.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8.7×10^5	1.5×10^5
16	62	691.9	669.9	11.5	15.5	7.1	6.9	31	15	25.3	26.4	23.7	15.5	40	15	--	--	--	--	--	--	--	--	--	--	--	--
17	63	890.2	--	11.0	13.0	7.1	6.8	68	22	--	--	--	--	81	14.4	--	--	--	--	--	--	--	--	--	--	--	--
18	64	907.3	--	11.5	14.0	7.1	6.8	35	14	59.6	27.3	--	--	64	12	19.5	17.9	16.9	11.9	0	4.8	2.6	2.6	2	2.2	--	--
19	65	565.5	557.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
20	66	565.5	557.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
21	67	565.5	557.5	10.0	15.0	7.6	7	77	18	291	45	--	--	--	--	41.3	29.2	34.1	23.3	0	4.7	6.6	4.6	3.5	3.9	--	--
22	68	1131.7	1022.0	12.0	14.0	7.3	7	68	20	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.7×10^5	2.0×10^5
23	69	--	843.3	9.0	14.0	7.2	6.8	34	8.3	79	28	66	18	81	19.4	--	--	--	--	--	--	--	--	--	--	--	--
24	70	654.8	651.0	10.0	17.0	7.1	7.1	24	12	--	--	--	--	43.5	25.5	--	--	--	--	--	--	--	--	--	--	--	--
25	71	590.1	571.2	11.0	17.5	7.2	7.1	22	17	29	44	--	--	34.5	17.4	--	--	--	--	--	--	--	--	--	--	--	--
26	72	432.2	420.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
27	73	432.2	420.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28	74	432.2	420.1	12.0	15.0	7.0	6.9	28	23	42	81	--	--	--	--	22.8	19	18.8	12.5	0	4.2	3.6	3.2	2.9	3	--	--
29	75	545.0	512.0	11.0	15.0	6.3	6.6	130	32	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.2×10^5	1.7×10^5
30	76	801.7	793.0	11.5	14.0	6.8	6.8	69	23	194	44	151	30	219	26.6	--	--	--	--	--	--	--	--	--	--	--	--
1 May	77	711.6	662.4	12.0	15.0	6.6	6.7	75	34	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2	78	839.1	808.5	13.0	15.0	6.4	6.6	38	18	66	35	--	--	148	42	16.9	13.4	15.2	10.3	0	0	2.8	4.1	3.1	3.8	--	--
3	79	807.7	742.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	80	807.7	742.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5	81	807.7	742.2	12.0	14.5	6.9	7.1	76	28	233	40.2	--	--	--	--	34	25.1	22.3	21.3	0	1	6.6	5.3	5	5.1	--	--
6	82	984.5	896.7	12.0	18.5	7.0	7.1	53	22	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.9×10^5	3.4×10^5
7	83	527.3	493.2	12.0	16.0	6.9	6.9	58	13	140	24	118	18	119	19.8	--	--	--	--	--	--	--	--	--	--	--	--
8	84	902.7	852.4	12.0	15.0	7.0	7.0	40	14	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9	85	796.0	752.5	12.0	--	6.9	7.1	36	16	44	26	--	--	97.5	38.4	28.8	26.6	24.9	21.6	0	1.2	5	5.2	4.4	4.8	--	--
10	86	771.4	727.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11	87	771.4	727.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	88	771.4	727.1	12.0	16.0	6.9	7.1	52	19	116	29	--	--	--	--	33	29.1	27	24.8	0	0.7	6.2	5.9	5.1	5.4	-	--
13	89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
14	90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
15	91	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16	92	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17	93	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
18	94	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
19	95	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
20	96	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4×10^5	0.34×10^5
21	97	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
22	98	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
23	99	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
24	100	915.6	811.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
25	101	915.6	811.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
26	102	915.6	811.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Date	Day no.	Flow liters applied	Flow liters runoff	Sewage temp. °C applied	Sewage temp. °C runoff	pH applied	pH runoff	Turbidity JTU applied	Turbidity JTU runoff	TSS mg/L applied	TSS mg/L runoff	VSS mg/L applied	VSS mg/L runoff	BOD_5 mg/L applied	BOD_5 mg/L runoff	Total N mg/L applied	Total N mg/L runoff	NH_3-N mg/L applied	NH_3-N mg/L runoff	NO_3-N mg/L applied	NO_3-N mg/L runoff	Total P mg/L applied	Total P mg/L runoff	PO_4-P mg/L applied	PO_4-P mg/L runoff	F. Col. no./100 ml applied	F. Col. no./100 ml runoff
27 May	103	915.6	811.1	15.0	18.0	6.6	6.9	38	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28	104	594.2	575.7	14.0	17.0	6.7	6.5	45	5.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
29	105	720.7	658.6	14.0	12.0	6.7	6.6	34	5	--	--	--	--	131	17	--	--	--	--	--	--	--	--	--	--	--	--
30	106	813.0	768.0	14.0	17.0	7.1	6.8	46	6.5	--	--	--	--	74	15.5	--	--	--	--	--	--	--	--	--	--	--	--
31	107	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1 Jun	108	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2	109	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3	110	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	111	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5	112	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6	113	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7	114	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
8	115	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9	116	--	--	14.0	16.0	6.6	6.7	20	5.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
10	117	1200.6	1100.3	12.0	16.0	6.4	6.8	85	3.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11	118	207.8	446.3	14.0	16.0	6.8	6.8	43	7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5.7×10^5	0.18×10^5
12	119	823.6	736.6	14.0	16.0	6.9	6.8	47	3.1	113	7.6	90	5.9	109	15.5	--	--	--	--	--	--	--	--	--	--	--	--
13	120	767.2	668.8	14.0	16.0	6.9	6.9	77	5.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
14	121	1958.7	1817.6	--	--	--	--	--	--	9.4	4.2	71	2.8	78	7.4	--	--	--	--	--	--	--	--	--	--	--	--
15	122	1958.7	1817.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16	123	1958.7	1817.6	16.0	18.0	6.7	6.5	35	2.8	91	4.4	74	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17	124	1661.6	1414.8	16.0	16.0	6.6	6.5	60	3.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
18	125	2664.6	2476.5	16.0	17.0	6.7	6.8	38	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
19	126	1657.5	1558.3	17.0	17.0	6.8	6.6	33	2.5	92	4	77	2.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--
20	127	923.9	840.6	17.0	18.0	6.7	6.4	33	1.5	--	--	--	--	69	6.3	--	--	--	--	--	--	--	--	--	--	--	--
21	128	2827.4	2659.7	--	--	--	--	--	--	4.6	4.6	36	2.9	47	4.2	--	--	--	--	--	--	--	--	--	--	--	--
22	129	2827.4	2659.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
23	130	2827.4	2659.7	17.0	17.0	6.6	6.7	30	4.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
24	131	1791.1	1631.3	14.3	17.0	6.6	6.7	4.7	5.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
25	132	1547.7	1542.4	14.5	17.0	9.6	9.3	34	18	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.6×10^5	1.0×10^5
26	133	--	--	--	--	--	--	--	--	--	--	--	--	37	18.3	--	--	--	--	--	--	--	--	--	--	--	--
27	134	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28	135	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
29	136	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
30	137	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

☆U.S. GOVERNMENT PRINTING OFFICE: 1982 – A-2076/386